Appendix H
Paired Watershed Regression Analysis

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This Appendix consists of three internal CH2M HILL memoranda that describe in detail the Paired Watershed regression analysis for total phosphorous, soluble reactive phosphorus, and total dissolved phosphorous.

MWTS Total Phosphorus Paired Watershed Analysis

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DATE: February 14, 2001

Results

North Site

TP concentrations in control cell 3 were used to predict the TP concentrations in the north site treatment cells 2 and 4 during the calibration period, combining CH2M HILL data with data collected by SFWMD starting in 1998. Strong one to one relationships were calculated for both control vs. treatment cell pairs. The variables were log10 transformed to control variance over the range of the predictor variables, and improve the distribution properties of the residuals. Robust regression was used to model the relationships, to reduce the influence of outliers and minor deviations from a normal distribution among error terms and inconstant variance.

The regression slope coefficient for cell 2 versus cell 3 during the calibration period was 0.9247 with an intercept of –0.1017 (Table 1). The intercept for the calibration regression equation for cell 2 vs. cell 3 was not significantly different from zero, but the slope coefficient was highly significant, with a p-value equal to 0.0000, indicating a strong, positive relationship between the control cell and treatment cell 2. The strong relationship between cell 2 and cell 3 during the calibration period is clearly seen in the first scatter plot of Figure 1, with the robust regression trend line showing the slope of 0.9247.

The regression slope coefficient for cell 4 versus cell 3 during the calibration period was 0.920 with an intercept of –0.0566 (Table 2). The intercept value is not significantly different from zero, but the slope coefficient for the calibration regression equation for cell 4 vs. cell 3 is very significantly different from zero, with p-value equal to 0.000, indicating a strong, positive relationship between the control cell and treatment cell 4. The strong relationship between cell 4 and cell 3 during the calibration period is clearly seen in the second scatter plot of Figure 1, with the robust regression trend line showing the slope of 0.920.

Data collected from the north site during the treatment period was also modeled using log10 transformations and robust regression. The calibration equations were used to predict the values that would have been observed in the treatment cells during the experimental treatment period, if no treatment had been applied, to determine the effect of the chemical treatment. The treatment period lasted from April to December, 2000. The predicted values for the treatment cells are represented by a dashed line in the plot of observed experimental data collected during the treatment period in Figure 2. The predicted values were calculated by inputting the data from the control cell 3 collected during the treatment period into the calibration equations to predict the values that would have been observed in the treatment cells during the treatment period if no treatment had been applied.

Robust regression was again used during the treatment period, since climatic influence causing high TP inputs during the summer months and the combination of data from two different labs during the experimental period, PPB and DB labs, caused considerable heteroskedasticity (inconstant variance) over the treatment time period, and slight heteroskedasticity over the x-ranges of the relationships between the control and treatment cells. In addition, several large outliers were present, and the robust regression and log transformation reduced the influence from both of these problems. The trend in the relationship between the observed experimental data was determined for the experimental period, and compared with the calibration equations in tables 1 and 2. The observed trend lines are shown as solid lines in Figure 2. In both treatment cells 2 and 4, a notable decrease in observed values is evident in the data, compared to the values predicted to occur if no treatment had been applied. In cell 2, the regression slope coefficient decreased from 0.9247 to 0.7011 between the calibration and treatment periods, and the y-intercept dropped from –0.1017 to –0.6532 log units. This indicates that the amount of TP in the treatment cell outflow dropped from 92 percent to 70 percent of that in the control cell after the treatment began, minus the intercept value of .6532 log units. In the treatment equation for cell 2 versus cell 3, the y-intercept is significantly different from zero, although it was not different from zero during the calibration period.

In cell 4, the regression slope coefficient dropped from 0.920 to 0.687, and the y-intercept dropped from –0.0566 to –0.7142. Both coefficients are significantly different from zero. The treatment equation indicates that the amount of TP in the treatment cell 4 outflow dropped from 92 percent to 68.7 percent of that in the control cell after the treatment began, minus the intercept value of 0.7142 log units.

It appears that the alum treatment may have caused a greater reduction in [TP] than the iron treatment, judging by the amount of vertical shift in the trend line between the two treatments. The average concentration of TP was 0.0307 mg/l in cell 2, compared with an average of 0.0238 mg/l in cell 4.

The differences in observed and predicted data are plotted over time in Figure 3. Most of the difference values are greater than zero, indicating the predicted values are greater than the observed values. The result of positive differences shows that the treatments had the effect of reducing TP concentration from that predicted to occur without the treatments. It appears that the differences were greater in the first half of the experimental period. It is unknown whether the greater differences were caused by problems with lab analysis or increased TP load during the rainy summer months. The decrease in variance of the differences correlates both with the change in laboratories, and the ending of the rainy season. In any case, the design of the paired watershed analysis is robust to such problems, as seen by the significant treatment and calibration equations.

The decrease in the slope and intercept coefficients between the calibration and treatment periods in cell 2 were confirmed to be significantly different, statistically, using an analysis of covariance (ANCOVA), presented in Table 4. The ANCOVA shows that the overall relationship between the treatment cell 2 and control cell 3 is significant throughout the experimental period, with a p-value of 0.0000 and F-test value equal to 152.8, and a confidence level greater than 99 percent. The analysis shows that the decrease in the y-intercepts from –0.1017 to –0.6532 is statistically significant, with a p-value equal to 0.0000. The ANCOVA shows that the decrease in the slope coefficients from 0.9247 to 0.7011 is statistically significant at the 95 percent confidence level, with a p-value equal to 0.0497.

The decrease in the regression intercept coefficients between the calibration and treatment periods in cell 4 were confirmed to be significantly different, statistically, using an analysis of covariance (ANCOVA), at confidence level of over 99 percent. The decrease in the slope coefficients was also shown to be statistically significant, with a slightly lower confidence level of 92.4 percent (Table 4). The ANCOVA shows that the overall relationship between the treatment cell 4 and control cell 3 is significant throughout the experimental period, with a p-value of 0.0000 and F-test value equal to 72.8, and a confidence level greater than 99 percent. The analysis shows that the decrease in the y-intercepts from –0.0566 to –0.7142 is statistically significant, with a p-value equal to 0.0000. The ANCOVA shows that the decrease in the slope coefficients from 0.920 to 0.687 is statistically significant at the 92.36 percent confidence level, with a p-value equal to 0.0764.

The fit of the calibration and treatment regression equations to the data were checked using residual plots and quantile-quantile (QQ) standard normal plots. The residual plots show that the residuals are scattered randomly, and that no trend remains in the residuals, showing good fit (Figure 4). There are some large outliers, such as the treatment regression for cell 4 versus 3, but that these points did not have high influence on the trend lines, since the robust regression method was used. The QQ plots (Figure 5), show that the residuals for the equations fit to the north site mostly conform to the normal distribution, except for the outliers, such as the treatment residuals for regression cell 4 vs. 3.

South Site

The main difference between the south site and the north site was a lower total phosphorus loading in the influent water in the south site. Results of the paired watershed analysis showed that some factor, possibly interacting with the very low TP concentration allowed release of extra phosphorus concentration from the substrate during the treatment period, resulting in higher effluent TP than influent TP concentration.

The regression slope coefficient for treatment cell 7 versus control cell 6 during the calibration period was 0.4012 with an intercept of –0.9148 (Table 3). The intercept and slope coefficients for the calibration regression equation for cell 7 vs. cell 6 were both significantly different from zero, with coefficient p-values equal to 0.0000 and 0.0002 respectively, indicating a strong, positive relationship between the control cell 6 and treatment cell 7. The relationship between the control and treatment cell is not a 1 to 1 relationship, as was seen in the north site cells (2, 3, and 4) but the overall model is significant, with an R-squared coefficient equal to 0.379. Slight differences between treatment and control cells or watersheds such as this are allowed in the paired watershed analysis, as long as the relationship remains significant over both the treatment and calibration periods. The relationship between cell 7 and cell 6 during the calibration period can be seen in the third scatter plot of Figure 1. The robust regression trend line is shown in the figure with slope of 0.4012, indicating that the concentration of TP in the outflow of cell 7 during the calibration period was approximately 40 percent that of the TP concentration of cell 6 minus the intercept value of 0.9148 log units, even without any treatment.

During the treatment period, the regression slope coefficient for the observed data in treatment cell 7 increased to 1.0497, from the calibration period slope of 0.4012. The intercept coefficient during the treatment period dropped to –0.0791, not significantly different from zero. The treatment period regression model was significant, with an R-squared value of 0.477. The ANCOVA model (Table 6) shows that the difference between the slope coefficients of the treatment and calibration period regression are significantly different, with a p-value equal to 0.0208, but that the difference between the intercept coefficients is not statistically significant.

The time series plot of the predicted values for cell 7, minus the observed values shows that the majority of the differences were negative. This indicates that the observed values of TP concentration were mostly greater during the treatment period than would have been predicted if no chemical treatment had been applied during the treatment period of the year 2000. It is possible that this result is an artifact of the poor laboratory results. When a different laboratory began doing the phosphorus analyses the differences between predicted and observed concentrations became slightly positive or not different . Another less likely possibility is that the sediments leached phosphorus during the treatment period.

Conclusions

The paired watershed analyses showed that the PACL and iron chemical treatments combined with the constructed wetland systems successfully removed TP from the outflow of the agricultural water in the north site where TP concentrations were high. The analysis shows that apparently the chemical treatment combined with the low influent TP concentration and wetland system in the south site caused a release of TP from the wetland substrate.

The analysis also showed that the paired watershed experimental design can be successfully applied to constructed wetlands, and may be a valuable addition to experimental applications to study water quality treatment in wetlands.

Table 1. Calibration and treatment equations for TP in Cell 2 versus Cell 3: Iron treatment versus control, in north site with high TP input.									
Calibration Equation, Robust Regression: ***Log10(TP, Cell 2) = -0.1017 + 0.9247 * Log10(TP, Cell 3)***									
Independent variable	Coefficient Estimate	Estimate Std. Error	Coefficient t-test value	Coefficient p-value	Model Residual Scale Estimate	Model F-test	Model p-value	Multiple R-squared	Sample Size
Intercept	-0.1017	0.0838	-1.2129	0.2357	0.08453	89.78	0.0000	0.5651	28
Log10(TP, Cell3)	0.9247	0.0504	18.3384	0.0000					
Treatment Period, Robust Regression: ***Log10(TP, Cell 2) = -0.6532 + 0.7011 * Log10(TP, Cell 3)***									
Intercept	-0.6532	0.1320	-4.9495	0.0001	0.1232	33.312	0.0000	0.5973	28
Log10(TP, Cell3)	0.7011	0.0928	7.5557	0.0000					

Table 2. Calibration and treatment equations for TP in Cell 4 versus Cell 3: Alum treatment versus control, in north site with high TP input.									
Calibration Equation, Robust Regression: ***Log10(TP, Cell 4) = -0.0566 + 0.920 * Log10(TP, Cell 3)***									
Independent variable	Coefficient Estimate	Estimate Std. Error	Coefficient t-test value	Coefficient p-value	Model Residual Scale Estimate	Model F-test	Model p-value	Multiple R-squared	Sample Size
Intercept	-0.0566	0.1295	-0.4372	0.6654	0.09014	82.11	0.0000	0.6586	28
Log10(TP, Cell3)	0.9200	0.0779	11.8111	0.0000					
Treatment Period, Robust Regression: ***Log10(TP, Cell 4) = -0.7142 + 0.687 * Log10(TP, Cell 3)***									
Intercept	-0.7142	0.2097	-3.4064	0.0028	0.1316	38.157	0.0000	0.6208	28
Log10(TP, Cell3)	0.6873	0.1466	4.6884	0.0001					

Table 3. Calibration and treatment equations for TP in Cell 7.versus Cell 6. Alum treatment versus control, in south site with low TP input.									
Calibration Equation, Robust Regression: ***Log10(TP, Cell 7) = -0.9148 + 0.4012 * Log10(TP, Cell 6)***									
Independent variable	Coefficient Estimate	Estimate Std. Error	Coefficient t-test value	Coefficient p-value	Model Residual Scale Estimate	Model F-test	Model p-value	Multiple R-squared	Sample Size
Intercept	-0.9148	0.1473	-6.3679	0.0000					
Log10(TP, Cell6)	0.4012	0.0953	4.2112	0.0002	0.1003	19.2421	.00000	0.3791	37
Treatment Period, Robust Regression: ***Log10(TP, Cell 7) = -0.0791 + 1.0497 * Log10(TP, Cell 6)***									
Intercept	-0.0791	0.2146	-0.3687	0.7162					
Log10(TP, Cell6)	1.0497	10.1561	6.7264	0.0000	0.1352	30.75912	0.0000	0.4773	21

Table 4. Analysis of covariance for paired watershed analysis of TP between Cell 2 and Cell 3. .					
	Df	SS	MS	F value	Pr(F)
Slope significance combined data set	1	2.9117	2.9117	152.8050	0.0000
Intercept – comparison calibration v treatment	1	0.5751	0.5751	30.1818	0.0000
Slopes comparison calibration v treatment	1	0.0773	0.0773	4.0587	0.0497
Residuals	47	0.8956	0.0191		

Table 5. Analysis of covariance for paired watershed analysis of TP between Cell 4 and Cell 3.					
	Df	SS	MS	F value	Pr(F)
Slope significance combined data set	1	1.6593	1.6594	72.8164	0.0000
Intercept – comparison calibration v treatment	1	1.2054	1.2054	52.8960	0.0000
Slopes comparison calibration v treatment	1	0.0748	0.0748	3.2824	0.0764
Residuals	47	1.0710	0.0228		

Table 6. Analysis of covariance for paired watershed analysis of TP between Cell 7 and Cell 6.					
	Df	SS	MS	F value	Pr(F)
Slope significance combined data set	1	0.9592	0.9592	40.2863	0.0000
Intercept – comparison calibration v treatment	1	0.0180	0.0180	0.7579	0.3877
Slopes comparison calibration v treatment	1	0.1347	0.1347	5.6592	0.0208
Residuals	47	1.3333	0.0238		

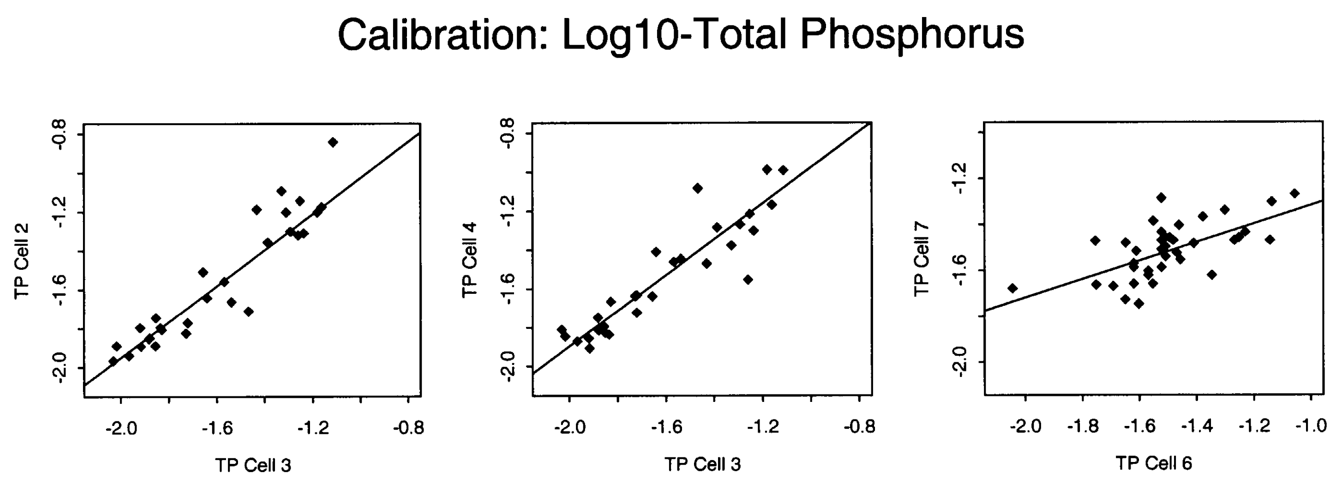

Figure 1. Treatment to control cell comparisons for the north site, for the calibration period only, with trend line.

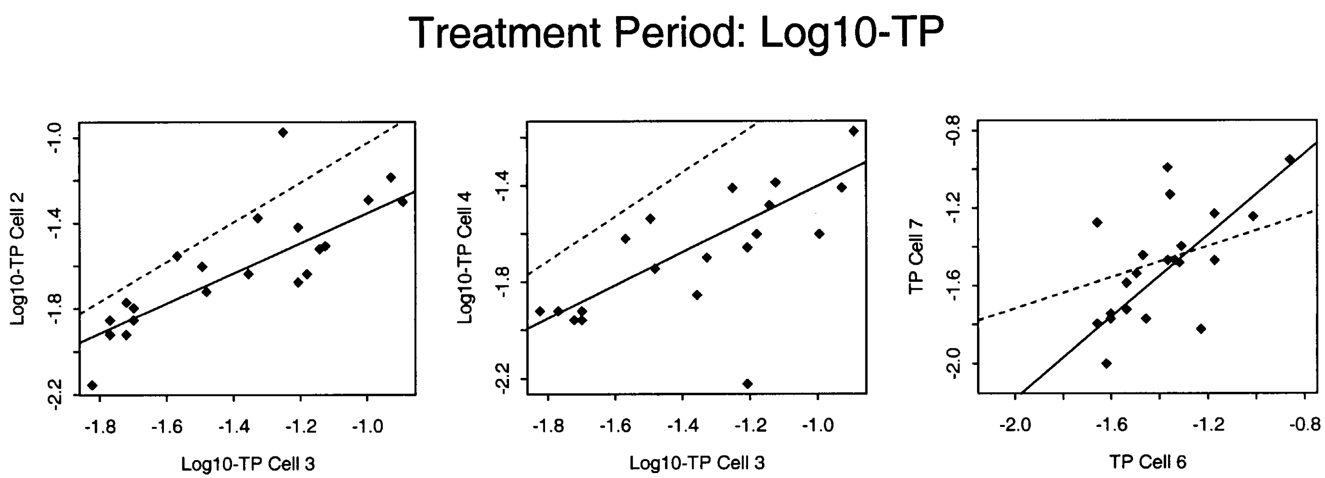

Figure 2. TP experimental treatment period: observed values with trend line (solid) plus line for predicted values (dashed) calculated from calibration equations.

Treatment Period: TP Predicted Minus Observed

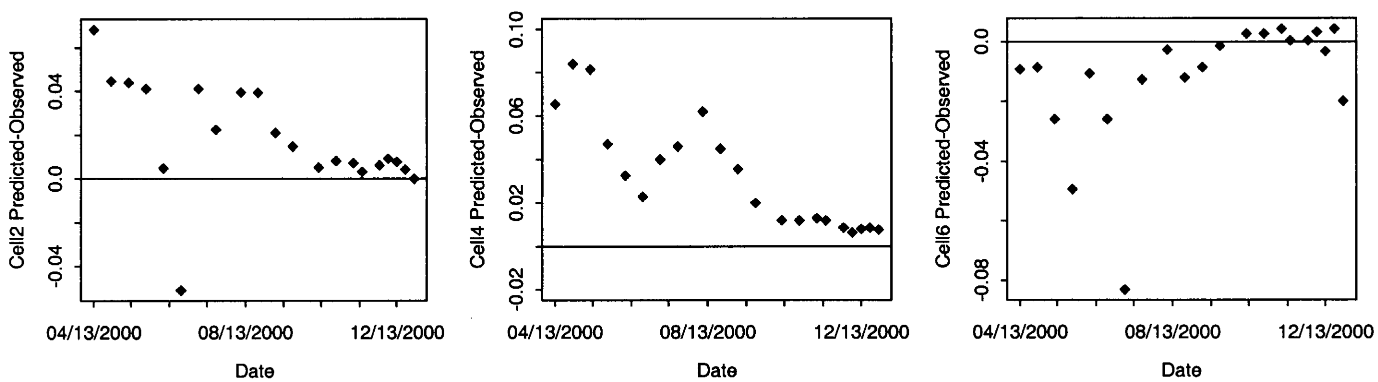

Figure 3. TP predicted minus observed values vs. date for experimental treatment period, for cell 2 and cell 4.

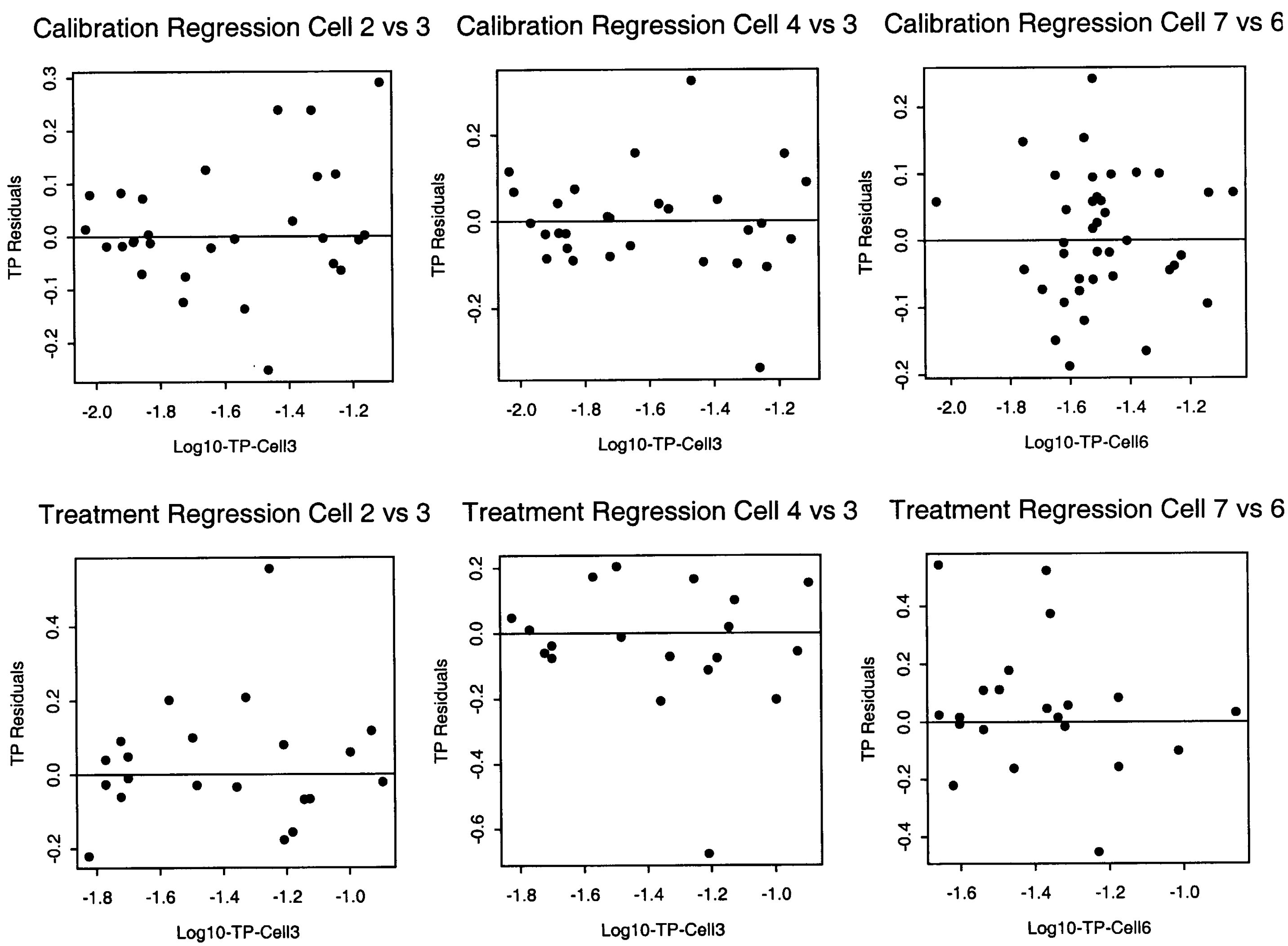

Figure 4. Plots of regression residuals for TP, calibration and treatment period equations.

QQ Normal Probability Plots: TP Robust Regression Residuals

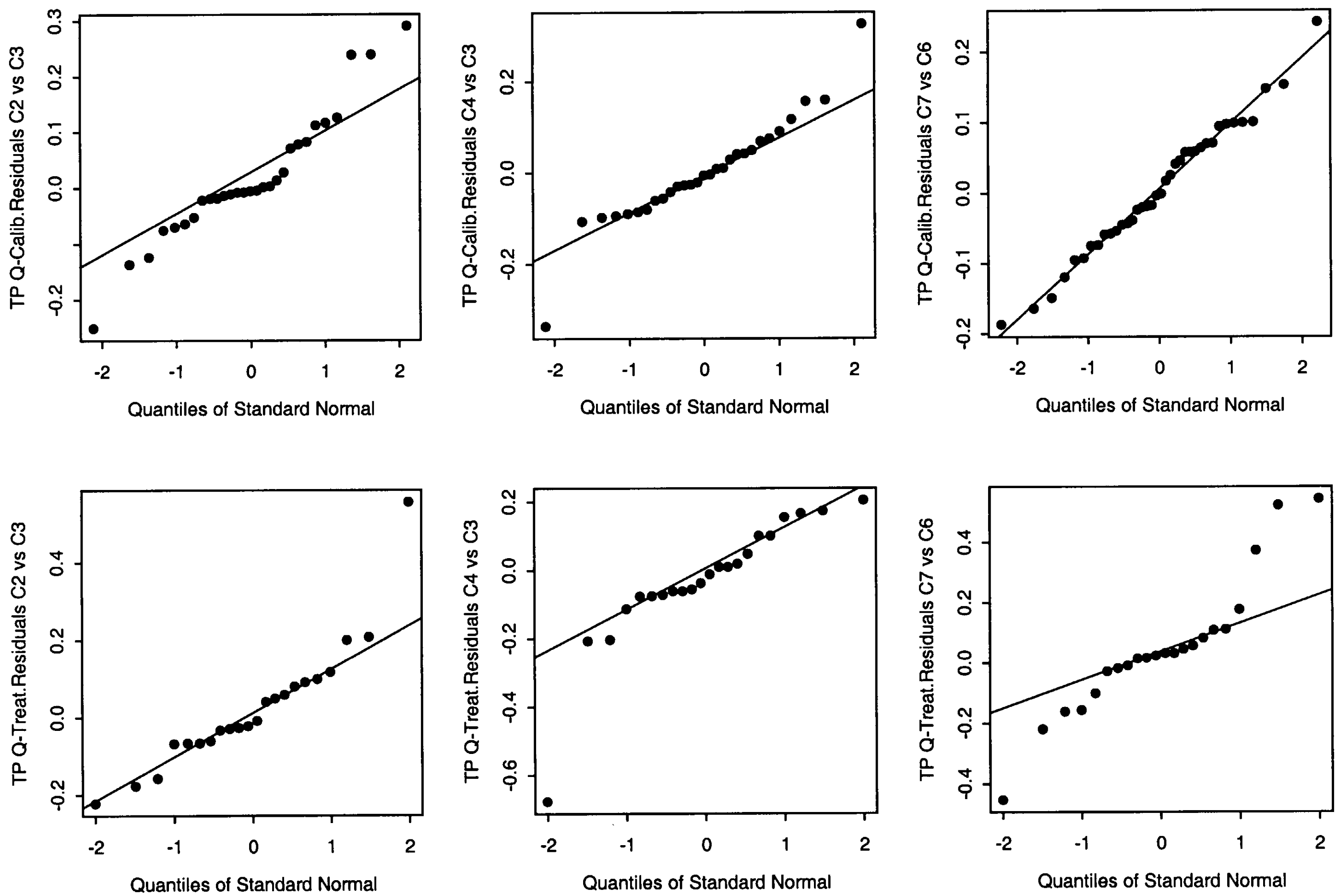

Figure 5. Standard normal quantile-quantile plots for TP regression residuals, calibration and treatment period equations.

MWTS Paired Watershed Analysis for SRP.

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DATE: April 19, 2001

Results

North Site

Concentrations of soluble reactive phosphorus (SRP) in control cell 3 were used to predict the SRP concentrations in the north site treatment cells 2 and 4 during the calibration period, combining CH2M HILL data with data collected by SFWMD starting in 1998. Robust regression and ordinary least squares (OLS) regression methods were compared to find the best fit model in all cases, plus comparisons of variable transformations were made for all variables. When necessary, the variables were log10 transformed to control variance over the range of the predictor variables, and improve the distribution properties of the residuals. Robust regression was used to model the relationships, to reduce the influence of outliers and minor deviations from a normal distribution among error terms and inconstant variance.

The regression slope coefficient for cell 2 versus cell 3 during the calibration period was 0.42857 with an intercept of –1.2551 (Table 1) with predictor and response variables log10 transformed. The intercept and slope coefficients for the calibration regression equation for cell 2 vs. cell 3 was both significantly different from zero with coefficient p-values equal to 0.0019 and 0.0089 respectively, indicating a moderate strong, positive relationship between the control cell and treatment cell 2. The overall model is significant, with a p-value equal to 0.0089, and R-squared value equal to 0.397. The relationship between cell 2 and cell 3 during the calibration period is shown in the first scatter plot of Figure 1, with the OLS regression trend line showing the slope of 0.4285. The OLS regression was used because the robust regression fit to these data down-weighted the points in the upper right–hand corner of the plot so much that the model resulted in a trend with a negative slope, and had residuals that showed a positive trend had been missed by the model (not shown). Since this result was not likely to be accurate, the OLS model was chosen, which although not strong, has a positive slope and random residuals with no trend apparent (Figure 4). Slight differences between treatment and control cells or watersheds such as this are allowed in the paired watershed analysis, as long as the relationship remains significant over both the treatment and calibration periods.

The regression slope coefficient for cell 4 versus cell 3 during the calibration period was 0.9437 with an intercept of –0.1094 (Table 2). The intercept value is not significantly different from zero, but the slope coefficient for the calibration regression equation for cell 4 vs. cell 3 is very significantly different from zero, with p-value equal to 0.000, indicating a strong, positive relationship between the control cell and treatment cell 4. The strong relationship between cell 4 and cell 3 during the calibration period is clearly seen in the second scatter plot of Figure 1, with the robust regression trend line showing the slope of 0.9437. The robust regression method was used to fit the model, and resulted in a significant model with an overall p-value equal to 0.0000 and an R-squared value equal to 0.61. Although the plot shows two high influence points in the upper right-hand corner, the robust regression determined that they are true outliers and consistent with the trend in the rest of the data.

Data collected from the north site during the treatment period was all modeled using log10 transformations and robust regression. The treatment period lasted from April to December, 2000. The predicted values for the treatment cells are represented by a dashed line in the plot of observed experimental data collected during the treatment period in Figure 2. The trend of the observed values is plotted with a solid line. The predicted values were calculated by inputting the data from the control cell 3 collected during the treatment period into the calibration equations to predict the values that would have been observed in the treatment cells during the treatment period if no treatment had been applied.

Robust regression was again used during the treatment period, since climatic influence causing high SRP inputs during the summer months and the combination of data from two different labs during the experimental period, PPB and DB labs, caused some heteroskedasticity inconstant variance) over the treatment time period, and slight heteroskedasticity over the x-ranges of the relationships between the control and treatment cells. In addition, several large outliers were present, and the robust regression and log10 transformation reduced the influence from both of these problems. The trends in the relationships between the observed treatment and control data were determined for the treatment period, and compared with the calibration equations in tables 1 and 2. The observed trend lines are shown as solid lines in Figure 2. In both treatment cells 2 and 4, a decrease in observed values is evident in the data plots, compared to the values predicted to occur if no treatment had been applied. In cell 2, the regression slope coefficient decreased from 0.4285 to 0.2881 between the calibration and treatment periods, and the y-intercept dropped from –1.2551 to –1.8097 log units (Table 1). This indicates that the amount of SRP in the treatment cell outflow dropped from 42.9 percent to 28.8 percent of that in the control cell after the treatment began, minus the intercept value of 1.8097 log units. In the treatment equation for cell 2 versus cell 3, the y-intercept is significantly different from zero with a p-value of 0.0000, and the slope coefficient is significant different from zero with a confidence level of 94.4 percent, and p-value equal to 0.0559. The overall treatment regression for cell 2 versus cell 3 is significant at the 93 percent confidence level, with a p-value of 0.0707.

In cell 4, the regression slope coefficient dropped from 0.9437 to 0.5353, and the y-intercept dropped from –0.1094 to –1.2465. Both coefficients are significantly different from zero. The treatment equation indicates that the amount of SRP in the treatment cell 4 outflow dropped from 94.4 percent to 53.5 percent of that in the control cell after the treatment began, minus the intercept value of 1.2465 log units.

It appears that the iron treatment combined with the natural treatment of wetland cell 2 may have caused a greater reduction in [SRP] than the alum treatment, judging by the average amount of SRP in the effluent from cell 2 versus cell 4. However, it appears that most of the decrease in SRP in the effluent from cell 2 was mostly caused by the natural treatment of the wetland cell 2 independent of the chemical treatment, since the calibration equation showed that cell 2 removed a significant amount of SRP during the calibration period, when no chemical treatment occurred. By visual inspection of the treatment period plots, it appears that the vertical shift in the trend line between the two treatments is greater in the alum treatment, cell 4. The average concentration of SRP was 0.0039 mg/l in cell 2, compared with an average of 0.0041 mg/l in cell 4.

The differences in observed and predicted data are plotted over time in Figure 3. Most of the difference values are greater than zero in the north site cells, indicating the predicted values are greater than the observed values. The result of positive differences shows that the treatments had the effect of reducing SRP concentration from that predicted to occur without the treatments. It appears that the differences were greater in the first half of the experimental period in cell 4, but roughly the same throughout the experimental period in cell 2. It is unknown whether the greater differences were caused by problems with lab analysis or increased SRP load during the rainy summer months. The decrease in variance of the differences correlates both with the change in laboratories, and the ending of the rainy season. In any case, the design of the paired watershed analysis is robust to such problems, as seen by the significant treatment and calibration equations.

The decrease in the slope coefficient between the calibration and treatment periods in cell 2 was confirmed to be significantly different, statistically, using an analysis of covariance (ANCOVA), presented in Table 4. However, the difference was found to marginally significant, with a confidence level of 90.9 percent, and a p-value of 0.0910. The slope coefficient dropped from 0.4285 to 0.2881, indicating that most of the decrease in SRP was not caused by the iron treatment, but by the natural wetland processes in cell 2, such as photosynthesis. The ANCOVA shows that the overall relationship between the treatment cell 2 and control cell 3 is significant throughout the experimental period, with a p-value of 0.0026 and F-test value equal to 10.58, and a confidence level equal to 99 percent. The analysis shows that the decrease in the y-intercepts from –1.2551 to –1.8097 is not statistically significant, with a p-value for the difference test equal to 0.7177.

The decrease in the regression slope coefficient between the calibration and treatment periods in cell 4 from 0.9437 to 0.5353 was confirmed to be significantly different, statistically, using an analysis of covariance (ANCOVA), at confidence level of 93.4 percent and a p-value equal to 0.0658. The decrease in the intercept coefficient was also shown to be statistically significant, with a confidence level of over 99 percent (Table 5). The ANCOVA shows that the overall relationship between the treatment cell 4 and control cell 3 is significant throughout the experimental period, with a p-value of 0.0000 and F-test value equal to 66.47, and a confidence level greater than 99 percent.

The fit of the calibration and treatment regression equations to the data were checked using residual plots and quantile-quantile (QQ) standard normal plots. The residual plots show that the residuals are mostly scattered randomly, and that no major trend remains in the residuals, showing good fit (Figure 4). There are some large outliers, such as the treatment regression for cell 2 versus 3, but that these points did not have high influence on the trend lines, since the robust regression method was used. The QQ plots (Figure 5), show that the residuals for the equations fit to the north site mostly conform roughly to the normal distribution, except for the outliers, such as the treatment residuals for regression cell 2 vs. 3. With such small data sets it can be difficult to determine the distribution properties of residuals, which is why the robust regressions are so important.

South Site

The main difference between the south site and the north site was a lower total phosphorus loading in the influent water in the south site. Results of the paired watershed analysis showed that some factor, possibly interacting with the very low TP concentration allowed release of extra phosphorus concentration from the substrate during the treatment period, resulting in higher effluent SRP than influent SRP concentration.

The calibration and treatment regression equations were fit using OLS regression, since the data relationship gave an odd set of weights to the robust regression and the technique was not able to fit a robust regression equation. The regression slope coefficient for treatment cell 7 versus control cell 6 during the calibration period was 0.9574 with an intercept of –0.1841 (Table 3). The slope coefficient for the calibration regression equation for cell 7 vs. cell 6 was both significantly different from zero, with coefficient p-value equal to 0.0000, indicating a strong, positive relationship between the control cell 6 and treatment cell 7. The intercept coefficient was not significantly different from zero, as would be expected in a 1 to 1 relationship. The R-squared coefficient equal to 0.699, a relatively high value. The relationship between cell 7 and cell 6 during the calibration period can be seen in the third scatter plot of Figure 1. The OLS regression trend line is shown in the figure with slope of 0.9574. This figure should be interpreted with caution, since there appears to be some heteroskedasticity and outliers, thus throwing question on the model fit. It would have been better to have a robust fit, if the method had been working in this case.

During the treatment period, the regression slope coefficient for the observed data in treatment cell 7 decreased to 0.6366, from the calibration period slope of 0.9574 (Table 3). The intercept coefficient during the treatment period dropped to –0.8522, significantly different from zero. The treatment period regression model was significant, with an R-squared value of 0.624. The ANCOVA model (Table 6) shows that the difference between the slope coefficients of the treatment and calibration period regression are significantly different, with a p-value equal to 0.0572, but that the difference between the intercept coefficients is not statistically significant. It appears that the predicted trend line is lower than the observed trend line for the treatment cell the third scatter plot of Figure 2. This indicates that more SRP was released in the effluent than was expected based on the calibration data.

The time series plot of the predicted values for cell 7, minus the observed values shows that the majority of the differences were negative. This indicates that the observed values of SRP concentration were mostly greater during the treatment period than would have been predicted if no chemical treatment had been applied during the treatment period of the year 2000. This result is difficult to explain, since there did not seem to be any release of SRP from the substrate during the calibration period.

The model fit between cells 7 and 6 was checked using diagnostic techniques including residual plots and QQ standard normal plots. The residuals plots showed that no apparent trend was overlooked in the data (Figure 4). The QQ normal plots show that some violation of the assumption of normality in the residuals may have been violated, especially in the calibration equation (Figure 5). The violation of normality is not as troublesome as some of the other problems, such as heteroskedasticity, and the model results should be interpreted with caution.

Conclusions

The paired watershed analyses showed that the PACL chemical treatment combined with the constructed wetland systems successfully removed SRP from the outflow of the agricultural water in the north site where TP concentrations were high. However, the iron treatment in cell 2 did not have as great an effect, and the effect was barely detectable. It seemed that some factor in the wetland cell 2 itself was more effective in reducing the SRP concentration.

The analysis shows that the chemical treatment combined with the low influent SRP concentration and wetland system in the south site may have caused a release of SRP and TP from the wetland substrate.

The analysis also showed that the paired watershed experimental design can be successfully applied to constructed wetlands, and may be a valuable addition to experimental applications to study water quality treatment in wetlands.

Table 1. Calibration and treatment equations for SRP in Cell 2 versus Cell 3: Iron treatment versus control, in north site with high TP input.									
Calibration Equation, OLS Regression: ***Log10(SRP, Cell 2) = -1.2551 + 0.4285 * Log10(SRP, Cell 3)***									
Independent variable	Coefficient Estimate	Estimate Std. Error	Coefficient t-test value	Coefficient p-value	Residual Standard Error	Model F-test	Model p-value	Multiple R-squared	Sample Size
Intercept	-1.2551	0.3286	-3.8194	0.0019	0.2097	9.201	0.0089	0.397	16
Log10(SRP, Cell3)	0.4285	0.1413	3.0334	0.0089					
Treatment Period, Robust Regression: ***Log10(SRP, Cell 2) = -1.8097 + 0.2881 * Log10(SRP, Cell 3)***									
					Residual Scale Estimate				
Intercept	-1.8097	0.3204	-5.6489	0.0000					21
Log10(SRP, Cell3)	0.2881	0.1419	2.0299	0.0559	0.1869	3.113	0.0707	0.1236	

Table 2. Calibration equation for SRP in Cell 4 versus Cell 3: Alum treatment versus control, in north site with high TP input.									
Calibration Period, Robust Regression Equation: ***Log10(SRP, Cell 4) = -0.1094 + 0.9437 * Log10(SRP, Cell 3)***									
Independent variable	Coefficient Estimate	Estimate Std. Error	Coefficient t-test value	Coefficient p-value	Model Residual Scale Estimate	Model F-test	Model p-value	Multiple R-squared	Sample Size
Intercept	-0.1094	0.1523	-0.7186	0.4842					
Log10(SRP, Cell3)	0.9437	0.0665	14.1970	0.0000	0.0891	35.416	0.0000	0.610	16
Treatment Period, Robust Regression Equation: ***Log10(SRP, Cell 4) = -1.2465 + 0.5353 * Log10(SRP, Cell 3)***									
Intercept	-1.2465	0.2288	-5.1146	0.0000					
Log10(SRP, Cell3)	0.5353	0.1027	5.2135	0.0000	0.1627	23.144	0.0000	0.525	21

Table 3. Calibration equation for SRP in Cell 7 versus Cell 6: Alum treatment versus control, in south site with low TP input.									
Calibration OLS Regression Equation: ***Log10(SRP, Cell 7) = -0.1841 + 0.9574 * Log10(SRP, Cell 6)***									
Independent variable	Coefficient Estimate	Estimate Std. Error	Coefficient t-test value	Coefficient p-value	Residual Standard Estimate	Model F-test	Model p-value	Multiple R-squared	Sample Size
Intercept	-0.1841	0.2509	-0.7335	0.4691					
SRP (Cell 6)	0.9574	0.1167	8.2005	0.0000	0.1682	67.25	0.0000	0.699	30
Treatment OLS Regression Equation: ***Log10(SRP, Cell 7) = -0.8522 + 0.6366 * Log10(SRP, Cell 6)***									
Intercept	-0.8522	0.2663	-3.2003	0.0045					
SRP (Cell 6)	0.6366	0.1105	5.7621	0.0000	0.1423	33.200	0.0000	0.6241	21

Table 4. Analysis of covariance for paired watershed analysis of SRP between Cell 2 and Cell 3.					
	Df	SS	MS	F value	Pr(F)
Slope significance combined data set	1	0.9288		10.5799	0.0026
Intercept – comparison calibration v treatment	1	0.2656		3.0253	0.0910
Slopes comparison calibration v treatment	1	0.0117		0.1329	0.7177
Residuals	34	2.9847	0.0878		

Table 5. Analysis of covariance for paired watershed analysis of SRP between Cell 4 and Cell 3.					
	Df	SS	MS	F value	Pr(F)
Slope significance combined data set	1	1.8385		66.4671	0.0000
Intercept – comparison calibration v treatment	1	0.6578		23.7833	0.0000
Slopes comparison calibration v treatment	1	0.0999		3.6136	0.0658
Residuals	34	0.9404	0.0277		

Table 6. Analysis of covariance for paired watershed analysis of SRP between Cell 7 and Cell 6.					
	Df	SS	MS	F value	Pr(F)
Slope significance combined data set	1	2.7282		109.0895	0.0000
Intercept – comparison calibration v treatment	1	0.0411		1.6427	0.2060
Slopes comparison calibration v treatment	1	0.0949		3.7936	0.0572
Residuals	49	1.2254	0.0250		

Calibration Period: Soluble Reactive Phosphorus

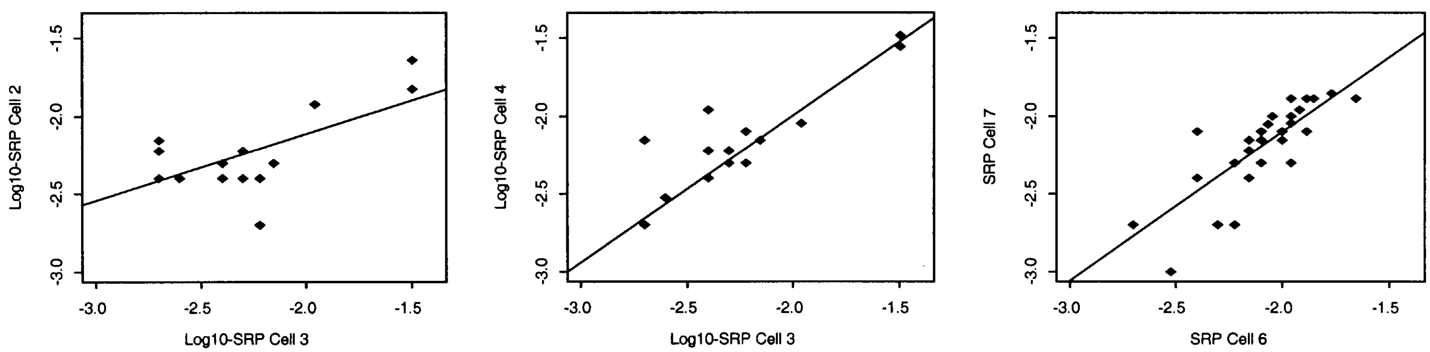


Figure 1. Scatter plots showing relation between the treatment and control cells during the calibration period, with trend lines. OLS regression was applied to the Cell 2 vs. Cell 3 PWA, robust regression was applied to the Cell 4 vs. Cell 3 and Cell 7 vs. Cell 6 PWA .

Treatment Period: Soluble Reactive Phosphorus

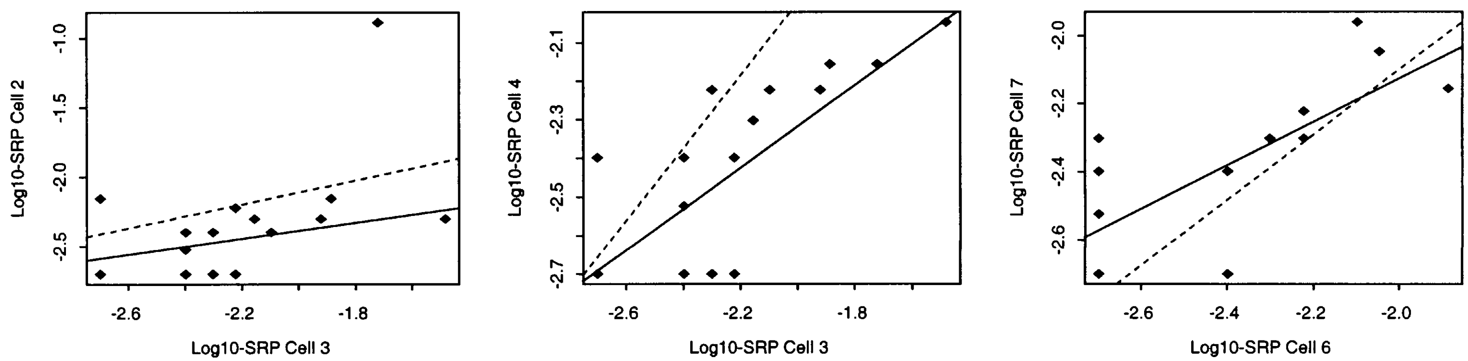


Figure 2. Scatter plots showing relationship between the treatment and control cells during the treatment period. Dashed line shows predicted trend line, solid line shows the observed trend line.

Treatment Period: SRP Predicted Minus Observed

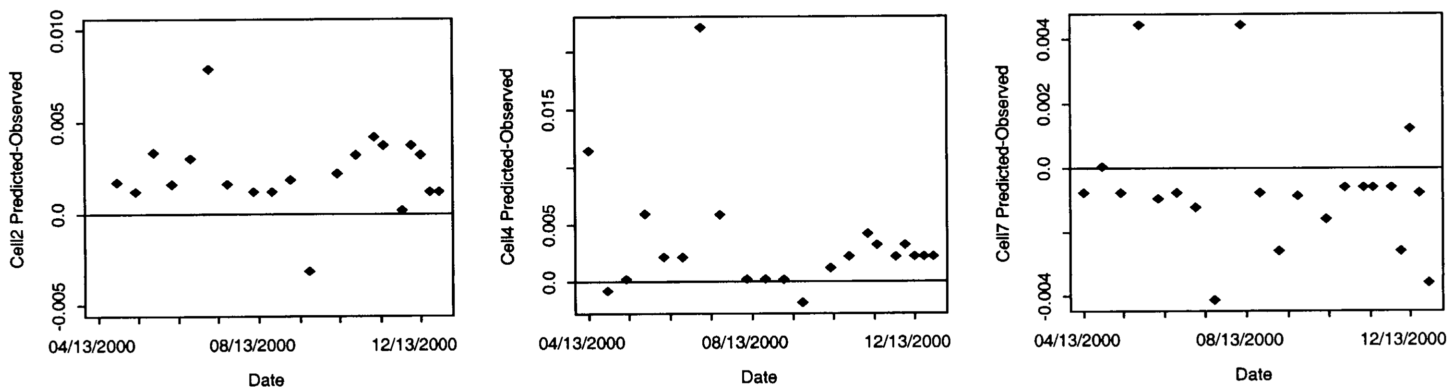


Figure 3. SRP predicted minus observed values for experimental treatment period, for treatment cells 2, 4 and 7.

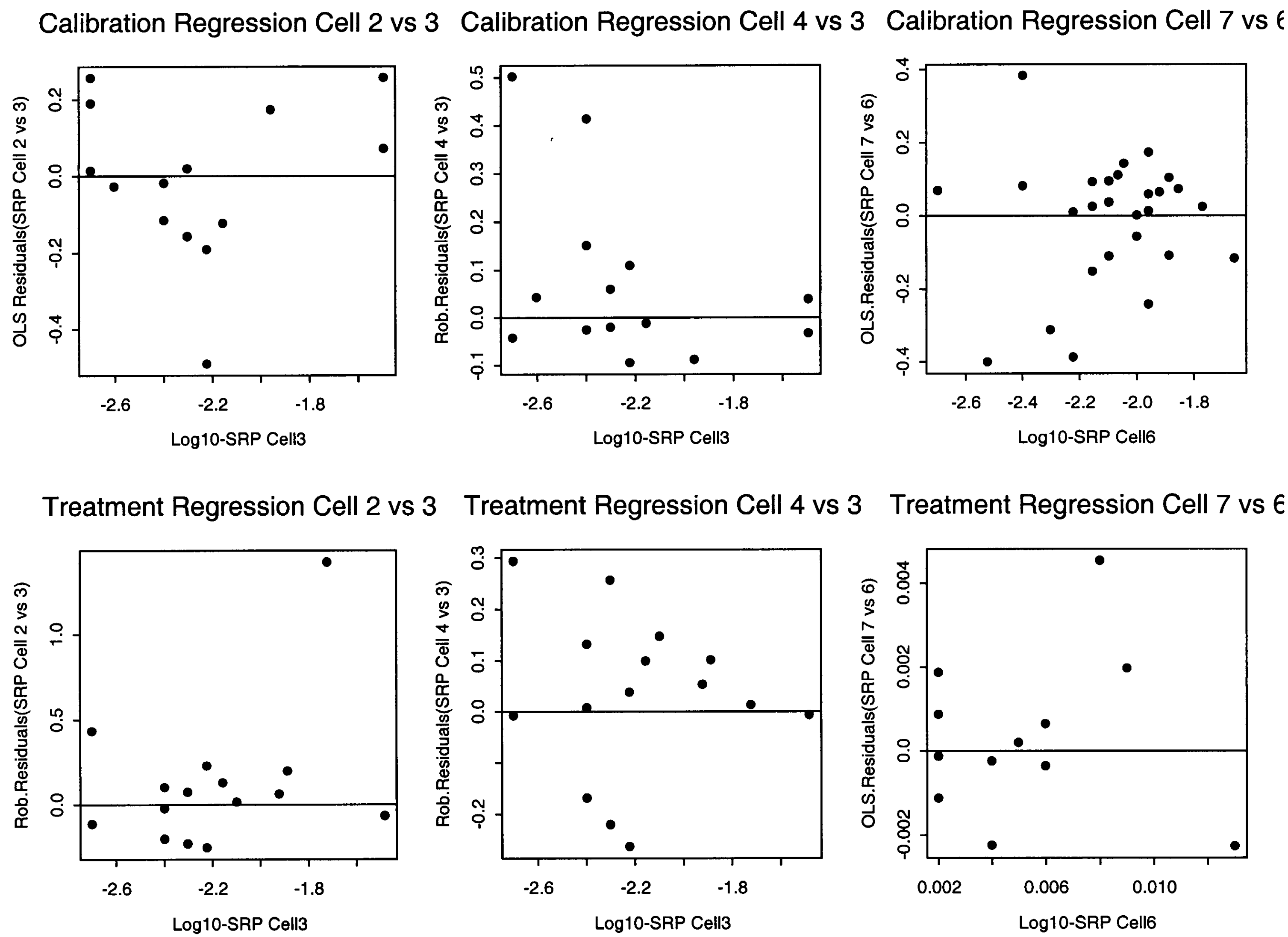
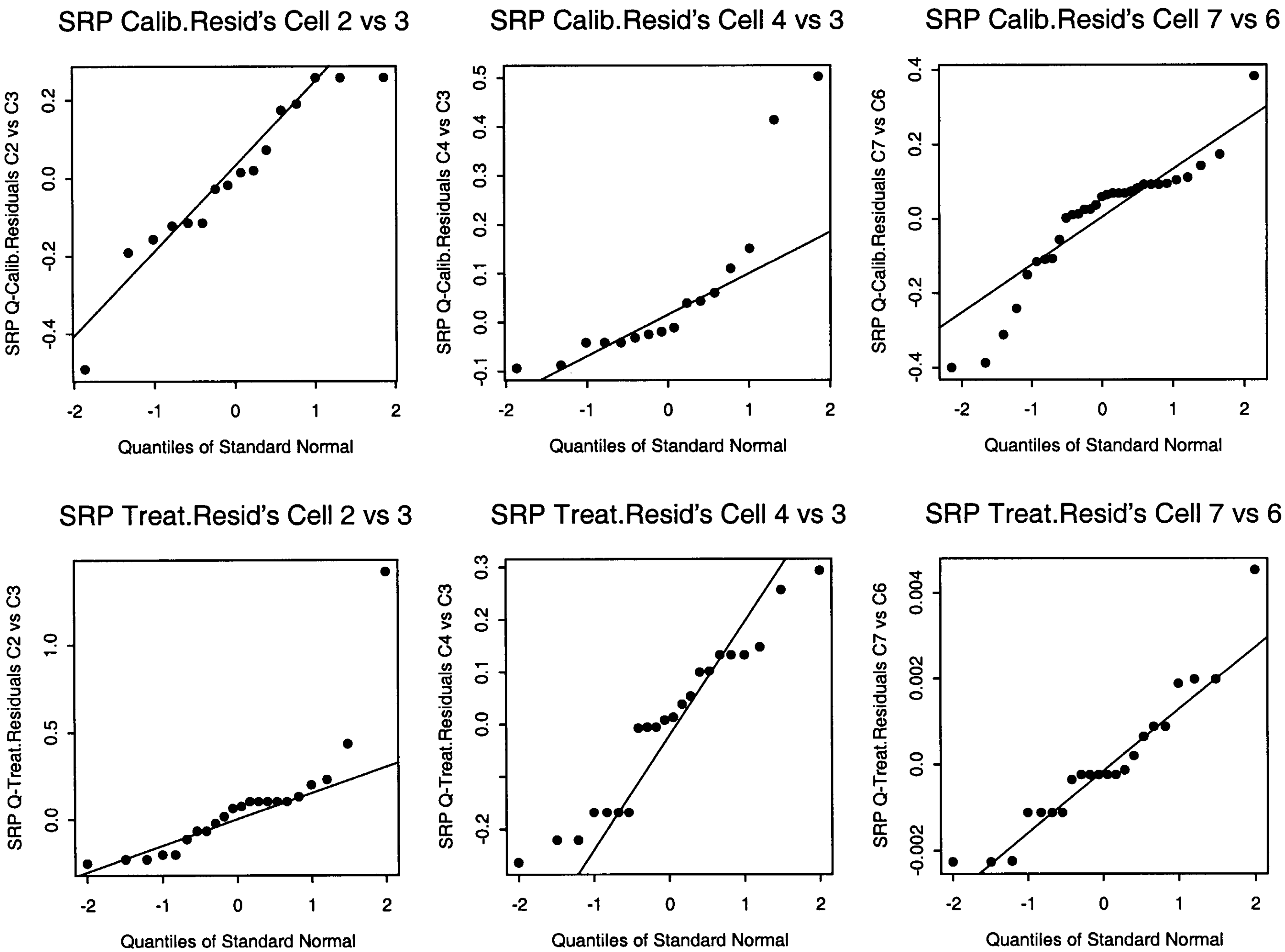


Figure 4. Residuals from calibration and treatment period regression equations.


SRP Calib.Resid's Cell 2 vs 3
SRP Q-Calib.Residuals C2 vs C3
Quantiles of Standard Normal
SRP Calib.Resid's Cell 4 vs 3
SRP Q-Calib.Residuals C4 vs C3
Quantiles of Standard Normal
SRP Calib.Resid's Cell 7 vs 6
SRP Q-Calib.Residuals C7 vs C6
Quantiles of Standard Normal
SRP Treat.Resid's Cell 2 vs 3
SRP Q-Treat.Residuals C2 vs C3
Quantiles of Standard Normal
SRP Treat.Resid's Cell 4 vs 3
SRP Q-Treat.Residuals C4 vs C3
Quantiles of Standard Normal
SRP Treat.Resid's Cell 7 vs 6
SRP Q-Treat.Residuals C7 vs C6
Quantiles of Standard Normal

MWTS TDP Calibration and Treatment Equations

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DATE: April 18, 2001

Results

North Site

Concentrations of total dissolved phosphorus (TDP) in control cell 3 were used to predict the TDP concentrations in the north site treatment cells 2 and 4 during the calibration period, combining CH2M HILL data with data collected by SFWMD starting in 1998. Robust regression and ordinary least squares (OLS) regression methods were compared to find the best fit model in all cases, plus comparisons of variable transformations were made for all variables. When necessary, the variables were log10 transformed to control variance over the range of the predictor variables, and improve the distribution properties of the residuals. Robust regression was used to model the relationships, to reduce the influence of outliers and minor deviations from a normal distribution among error terms and inconstant variance.

The regression slope coefficient for cell 2 versus cell 3 during the calibration period was 0.7794 an intercept of –0.3312 (Table 1) with predictor and response variables log10 transformed. The intercept and slope coefficients for the calibration regression equation for cell 2 vs. cell 3 were not significantly different from zero with coefficient p-values close to 1.0. However, the overall regression was highly significant. This apparently contradictory result is caused by the conservative estimation procedure for the estimates of coefficient standard errors in the non-parametric method. , The overall model is significant, with a p-value equal to 0.012, and R-squared value equal to 0.5241. The relationship between cell 2 and cell 3 during the calibration period is shown in the first scatter plot of Figure 1.

The regression slope coefficient for cell 4 versus cell 3 during the calibration period was 0.5535 with an intercept of –0.7387 (Table 2). The intercept value is not significantly different from zero, but the slope coefficient for the calibration regression equation for cell 4 vs. cell 3 is significantly different from zero, with p-value equal to 0.0326 indicating a positive relationship between the control cell and treatment cell 4. The strong relationship between cell 4 and cell 3 during the calibration period is clearly seen in the second scatter plot of Figure 1. The robust regression method was used to fit the model, and resulted in a significant model with an overall p-value equal to 0.0004 and an R-squared value equal to 0.45. Although the plot shows two high influence points in the upper right-hand corner, the robust regression determined that they are true outliers and consistent with the trend in the rest of the data.

Data collected from the north site during the treatment period was all modeled using log10 transformations and robust regression. The treatment period lasted from April to December, 2000. The predicted values for the treatment cells are represented by a dashed line in the plot of observed experimental data collected during the treatment period in Figure 2. The trend of the observed values is plotted with a solid line. The predicted values were calculated by inputting the data from the control cell 3 collected during the treatment period into the calibration equations to predict the values that would have been observed in the treatment cells during the treatment period if no treatment had been applied.

Robust regression was again used since climatic influence causing high TDP inputs during the summer months and the combination of data from two different labs during the experimental period, PPB and DB labs, caused some heteroskedasticity (inconstant variance) over the treatment time period, and slight heteroskedasticity over the x-ranges of the relationships between the control and treatment cells. In addition, several large outliers were present, and the robust regression and log10 transformation reduced the influence from both of these problems. The trends in the relationships between the observed treatment and control data were determined for the treatment period, and compared with the calibration equations in tables 1 and 2. The observed trend lines are shown as solid lines in Figure 2. In both treatment cells 2 and 4, a decrease in observed values is evident in the data plots, compared to the values predicted to occur if no treatment had been applied. In cell 2, the regression slope coefficient increased slightly from 0.7794 to 0.8535 between the calibration and treatment periods, and the y-intercept dropped only slightly. (Table 1). This indicates that the amount of TDP in the treatment cell outflow changed very little during the treatment period.

In cell 4, the regression slope coefficient increased from 0.5535 to 1.0098 and the y-intercept dropped from –0.7387 to –0.2541. the treatment period intercept was not significantly different from zero, while the slope coefficient was highly significant. The treatment equation indicates that the amount of TDP in the treatment cell 4 outflow increased related to that of the control cell after the treatment began, minus the intercept value.

Visual inspection of the treatment period plots support the regression results and suggest that there is relatively little trend in TDP changes with treatment.

The differences in observed and predicted data are plotted over time in Figure 3. Most of the difference values are greater than zero in the north site cells, indicating the predicted values are greater than the observed values. The result of positive differences shows that the treatments had the effect of reducing TDP concentration from that predicted to occur without the treatments. It appears that the differences were greater in the first half of the experimental period in cell 2, but roughly the same throughout the experimental period in cell 4. This is the opposite of the results with SRP. It is unknown whether the greater differences were caused by problems with lab analysis or increased TDP load during the rainy summer months. The decrease in variance of the differences correlates both with the change in laboratories, and the ending of the rainy season. by the significant treatment and calibration equations.

The lack of differentiation between calibration and treatment period in the slope coefficient between the calibration and treatment periods in cell 2 was confirmed with ANCOVA (Table 4). The intercepts were found to be highly significantly different (Pr(F) = 0.0001, Table 4)

The ANCOVA analysis revealed that while the combined data set was significantly different from the calibration regression, there was no significant difference between the calibration and treatment period regressions (Table 5).

The fit of the calibration and treatment regression equations to the data were checked using residual plots and quantile-quantile (QQ) standard normal plots. The residual plots show that the residuals are mostly scattered randomly, and that no major trend remains in the residuals, showing good fit (Figure 4). There are some large outliers, such as the calibration and treatment regressions for NTC 4 versus NTC 3, but that these points did not have high influence on the trend lines, since the robust regression method was used. The QQ plots (Figure 5), show that the residuals for the equations fit to the north site mostly conform roughly to the normal distribution, except for the treatment period comparing cell 4 and cell 3.

South Site

The main difference between the south site and the north site was a lower total phosphorus loading in the influent water in the south site. Results of the paired watershed analysis showed that some factor, possibly interacting with the very low TP concentration allowed release of extra phosphorus concentration from the substrate during the treatment period, resulting in higher effluent SRP than influent SRP concentration.

The calibration and treatment regression equations were fit using OLS regression, since the data relationship gave an odd set of weights to the robust regression and the technique was not able to fit a robust regression equation. The regression slope coefficient for treatment cell 7 versus control cell 6 during the calibration period was 0.8595 with an intercept of –0.4234 (Table 3). The slope coefficient for the calibration regression equation for cell 7 vs. cell 6 was significantly different from zero positive relationship between the control cell 6 and treatment cell 7. The intercept coefficient was not significantly different from zero, as would be expected in a 1 to 1 relationship. The R-squared coefficient equal to 0.3802 a relatively low value. The relationship between cell 7 and cell 6 during the calibration period can be seen in the third scatter plot of Figure 1. This figure should be interpreted with caution, since there appears to be some heteroskedasticity and outliers, thus throwing question on the model fit.

During the treatment period, the regression slope coefficient for the observed data in treatment cell 7 increased to 1.1622 from the calibration period slope of 0.8595 (Table 3). The intercept coefficient during the treatment period also increased, to 0.1697, but not significantly different from zero. The treatment period regression model was significant, with an R-squared value of 0.4192, again, not a strong relationship. The ANCOVA model (Table 6) shows that the there was not significant difference between intercepts or slopes of the calibration and treatment periods for the STC 7 v STC 6 regressions.

The time series plot of the predicted values for cell 7, minus the observed values shows that the majority of the differences were negative. This indicates that the observed values of TDP concentration were mostly greater during the treatment period than would have been predicted if no chemical treatment had been applied during the treatment period of the year 2000. It seems most likely that this odd result is caused by the very small sample size that was available for analysis in this case.

The model fit between cells 7 and 6 was checked using diagnostic techniques including residual plots and QQ standard normal plots. The residuals plots showed that no apparent trend was overlooked in the data (Figure 4). The QQ normal plots show that some violation of the assumption of normality in the residuals may have been violated, especially in the calibration equation (Figure 5). The violation of normality is not as troublesome as some of the other problems, such as heteroskedasticity, and the model results should be interpreted with caution.

Conclusions

The paired watershed analyses showed that the TDP data sets did not provide a great deal of information about the difference between calibration and treatment periods. The small data sets and relatively low levels of total variance accounted for by the regression models suggest that the amount of information available for analysis was insufficient to draw any clear conclusions about the effect of the treatment regimes on total dissolved phosphorus in these systems.

Table 1. Calibration and treatment equations for TDP in Cell 2 versus Cell 3: Iron treatment versus control, in north site with high TP input.									
Calibration Equation, Robust Regression: ***Log10(TDP, Cell 2) = -0.3312 + 0.7794 * Log10(TDP, Cell 3)***									
Independent variable	Coefficient Estimate	Estimate Std. Error	Coefficient t-test value	Coefficient p-value	Model Residual Scale Estimate	Model F-test	Model p-value	Multiple R-squared	Sample Size
Intercept	-0.3312	13.5895	-0.0244	0.9810					
Log10(TDP, Cell3)	0.7794	8.6687	0.0899	0.9301	0.1486	10.0005	0.0012	0.5241	11
Treatment Period, Robust Regression: ***Log10(TDP, Cell 2) = -0.4611 + 0.8535 * Log10(TDP, Cell 3)***									
Intercept	-0.4611	0.3226	-1.4293	0.1691					
Log10(TDP, Cell3)	0.8535	0.1924	4.4358	0.0003	0.2047	16.9092	0.00	0.494	

Table 2. Calibration equation for TDP in Cell 4 versus Cell 3: Alum treatment versus control, in north site with high TP input.									
Calibration Period, Robust Regression Equation: ***Log10(TDP, Cell 4) = -0.7387 + 05535 * Log10(TDP, Cell 3)***									
	Coefficient Estimate	Estimate Std. Error	Coefficient t-test value	Coefficient p-value	Model Residual Scale Estimate	Model F-test	Model p-value	Multiple R-squared	Sample Size
Intercept	-0.7387	0.3518	-2.0996	0.0621					
Log10(TDP, Cell3)	0.5535	0.2232	2.4798	0.0326	0.0964	11.9322	0.0004	.4526	
Treatment Period, Robust Regression Equation: ***Log10(TDP, Cell 4) = -0.2541 + 1.0098 * Log10(TDP, Cell 3)***									
Intercept	-0.2541	0.2397	-1.0602	0.3023					
Log10(TDP, Cell3)	1.0098	0.1441	7.0081	0.0000	0.1514	22.5249	0.0000	0.4192	

Table 3. Calibration equation for TDP in Cell 7 versus Cell 6: Alum treatment versus control, in south site with low TP input.									
Calibration OLS Regression Equation: ***Log10(TDP, Cell 7) = -0.4234 + 0.8595 * Log10(TDP, Cell 6)***									
	Coefficient Estimate	Estimate Std. Error	Coefficient t-test value	Coefficient p-value	Model Residual Scale Estimate	Model F-test	Model p-value	Multiple R-squared	Sample Size
Intercept	-0.4234	0.3340	-1.2677	0.2336					
TDP (Cell 6)	0.8595	0.2177	3.9486	0.0027	0.182	5.3743	0.0176	0.3802	
Treatment OLS Regression Equation: ***Log10(TDP, Cell 7) = 0.1697 + 1.1622 * Log10(TDP, Cell 6)***									
Intercept	0.1697	0.7907	0.2146	0.8324					
TDP (Cell 6)	1.1622	0.4774	2. 4343	0.0250	0.2273	16.9192	0.0002	0.4218	

Table 4. Analysis of covariance for paired watershed analysis of TDP between Cell 2 and Cell 3. .					
	Df	SS	MS	F value	Pr(F)
Slope significance combined dataset	1	1.1604	1.1604	36.5238	0.0000
Intercept – comparison calibration v treatment	1	0.60579	0.60579	19.0669	0.0001
Slopes comparison calibration v treatment	1	0.00571	0.00571	0.18.133	0.8724
Residuals	29	0.9214	0.0318		

.Table 5. Analysis of covariance for paired watershed analysis of TDP between Cell 4 and Cell 3.					
	Df	SS	MS	F value	Pr(F)
Slope significance combined dataset	1	0.9730	0.9730	23.2430	0001
Intercept – comparison calibration v treatment	1	0.5089	0.5089	12.1569	0.1610
Slopes comparison calibration v treatment	1	0.0011	0.0011	0.0263	0.1008
Residuals	29	1.2140			

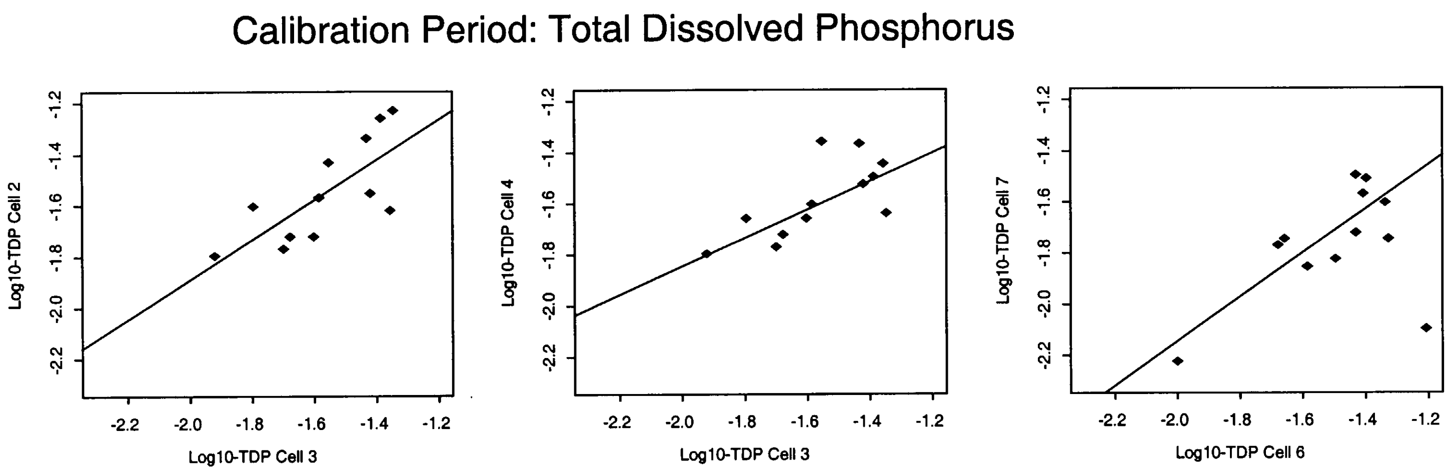

Figure 1. Scatter plots showing relation between the treatment and control cells during the calibration period, with trend lines. Robust regression was applied to determine all of the trend lines.

Treatment Period: Total Dissolved Phosphorus

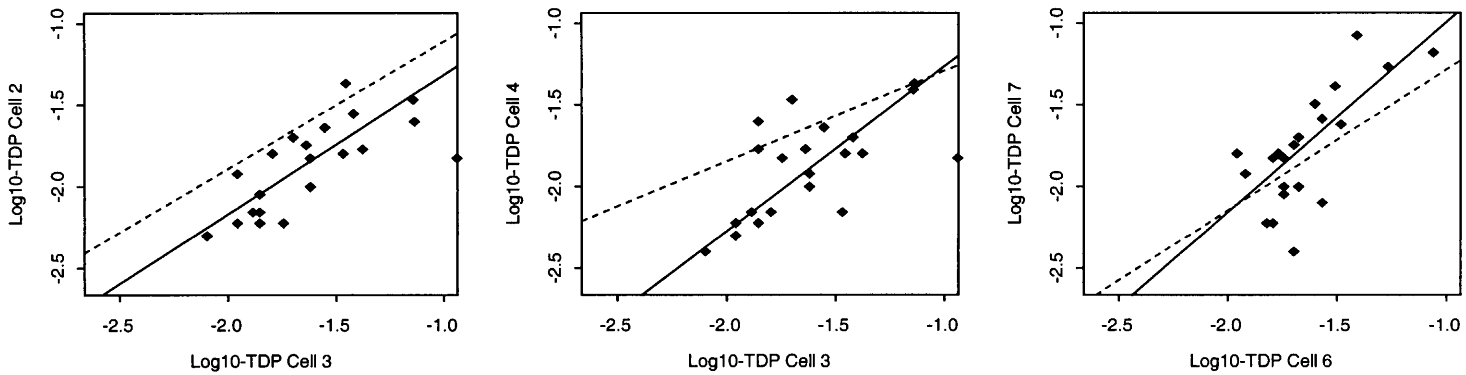

Figure 2. Scatter plots showing relationship between the treatment and control cells during the treatment period. Dashed line shows predicted trend line, solid line shows the observed trend line.

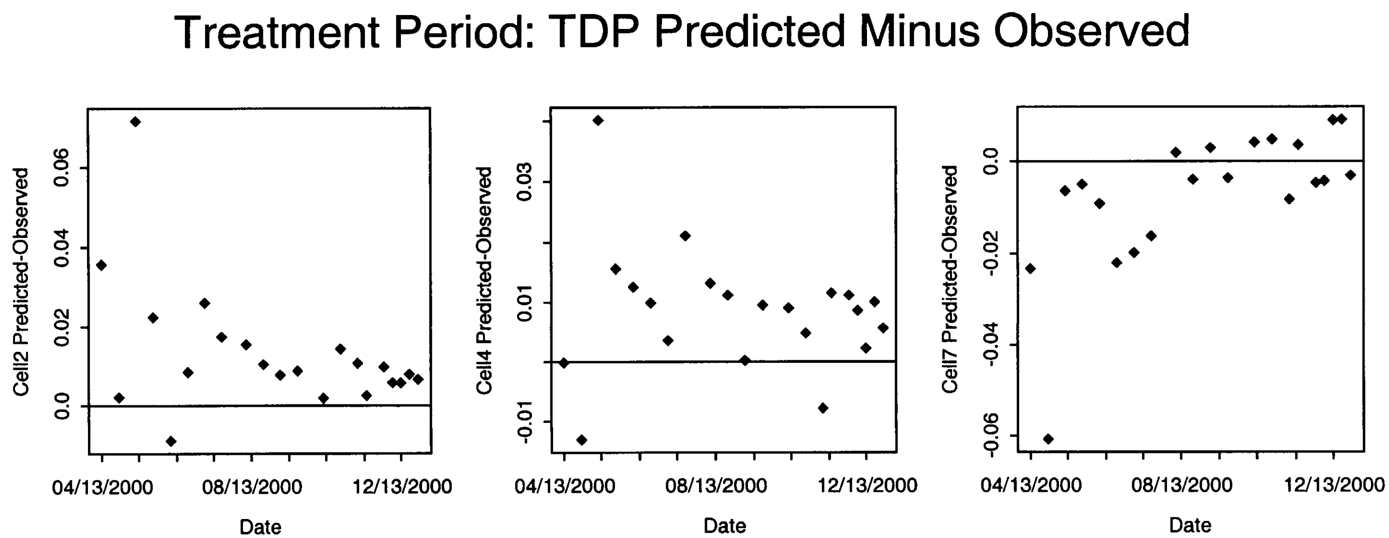

Figure 3. TDP predicted minus observed values for experimental treatment period, for treatment cells 2, 4 and 7.

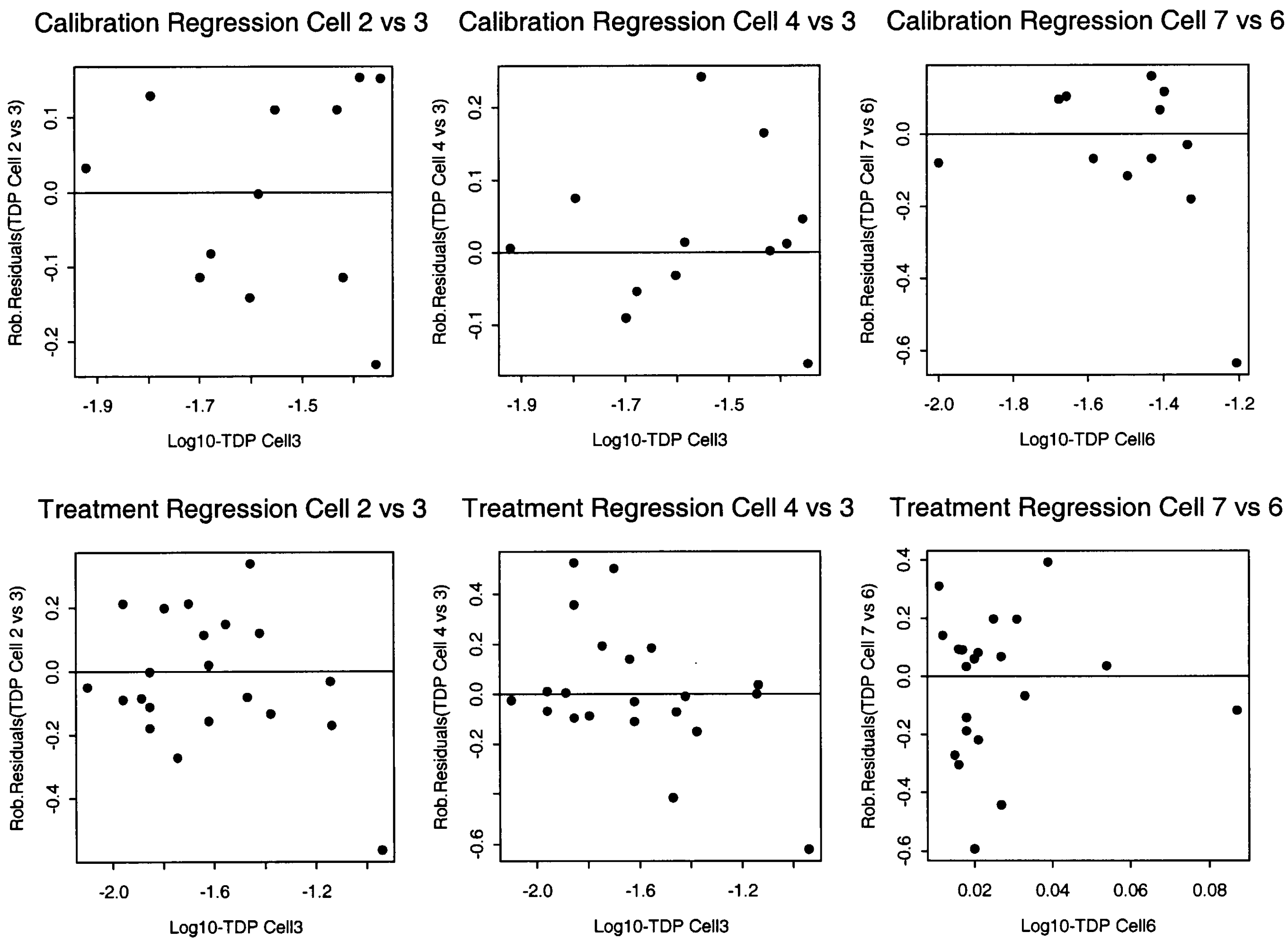

Figure 4. Residuals from calibration and treatment period regression equations.

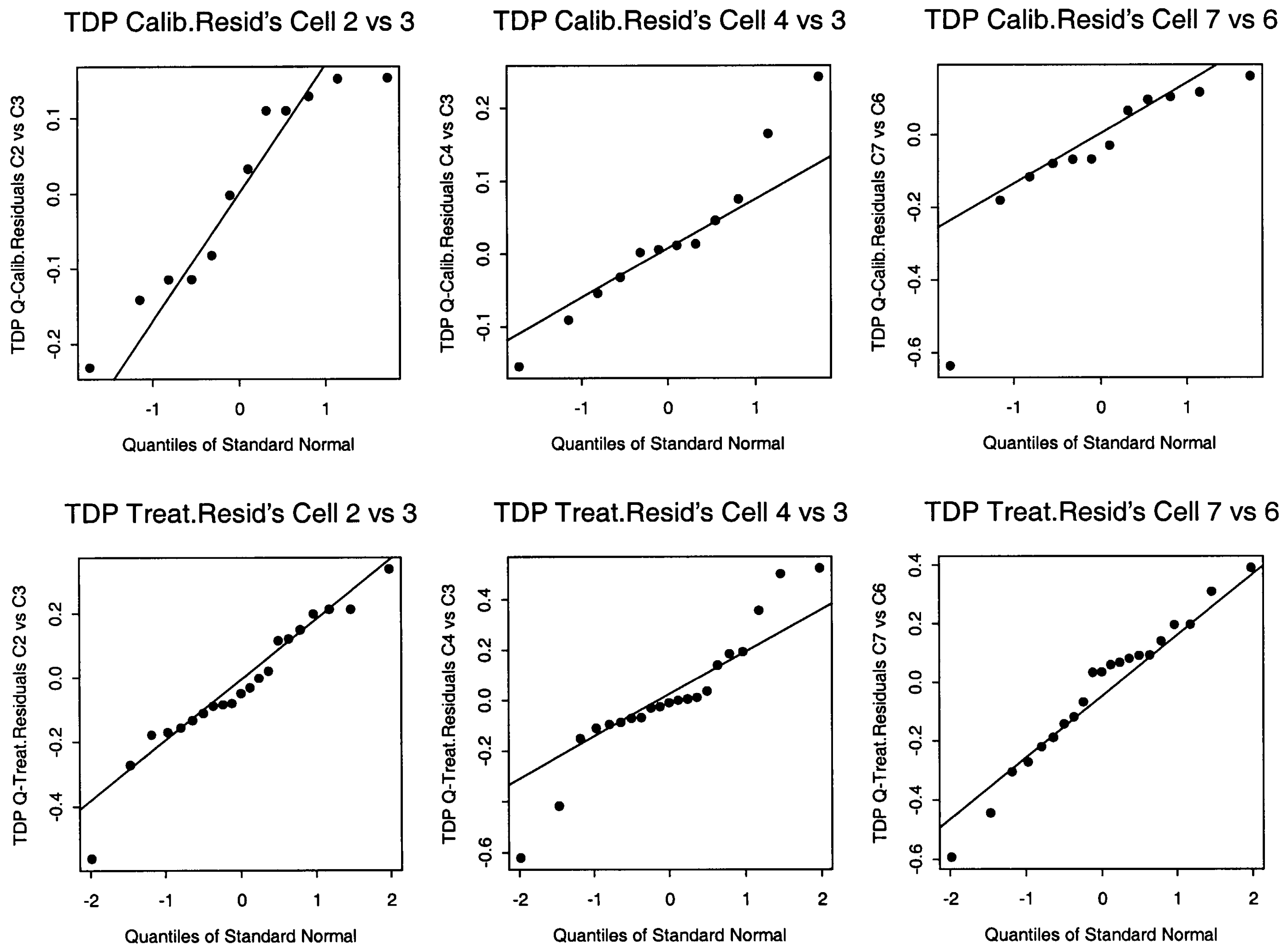

Figure 5 Robust regression residuals analysis using Q-Q normal probability plots.